Critique of Accelerator Technology

NLC

TESLA

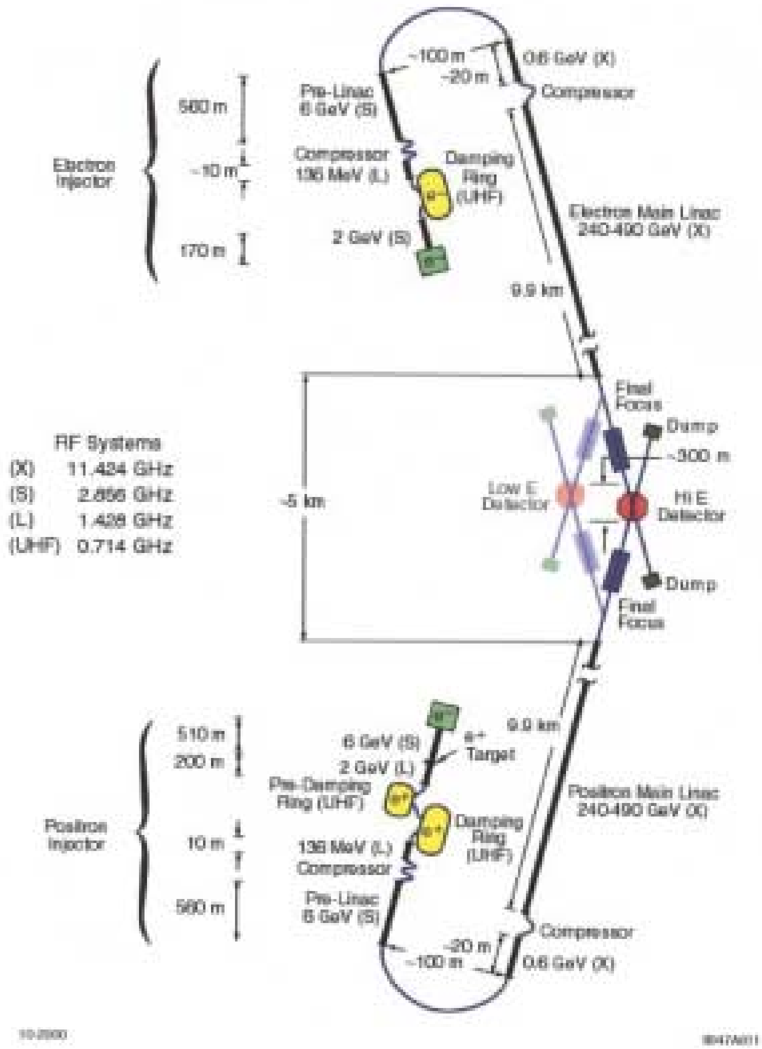
Muon Storage Rings

VLHC

Conclusions

NLC Parameters for 500 GeV and 1 TeV

IP Parameters for the JLC / NLC (2/24/00)								
	500 GeV				1 TeV			
	A	B	C	H	A	B	C	H
CMS Energy (GeV)	510	500	482	490	1022	1000	964	888
Luminosity (10^{33})	**5.3**	**5.4**	**5.5**	**22**	**10.6**	**10.8**	**11**	**34**
Repetition Rate (Hz)	120	120	120	120	120	120	120	120
Bunch Charge (10^{10})	**0.7**	**0.82**	**1**	**0.75**	**0.7**	**0.82**	**1**	**0.75**
Bunches/RF Pulse	95	95	95	190	95	95	95	190
Bunch Separation (ns)	2.8	2.8	2.8	1.4	2.8	2.8	2.8	1.4
Eff. Gradient (MV/m)	**58.7**	**57.3**	**55.2**	**50.2**	**58.7**	**57.3**	**55.2**	**50.2**
Injected $\gamma\varepsilon_x$ / $\gamma\varepsilon_y$ (10^{-8})	300 / 3	300 / 3	300 / 3	300 / 2	300 / 3	300 / 3	300 / 3	300 / 2
$\gamma\varepsilon_x$ at IP (10^{-8} m-rad)	400	450	500	360	400	450	500	360
$\gamma\varepsilon_y$ at IP (10^{-8} m-rad)	**6.5**	**8.5**	**12**	**3.5**	**6.5**	**8.5**	**12**	**3.5**
β_x / β_y at IP (mm)	12 / 0.12	12 / 0.12	13 / 0.15	8 / 0.10	12 / 0.12	12 / 0.15	13 / 0.15	10 / 0.12
σ_x / σ_y at IP (nm)	**310 / 4.0**	**330 / 4.6**	**365 / 6.2**	**245 / 2.7**	**220 / 2.8**	**235 / 3.2**	**260 / 4.4**	**200 / 2.2**
σ_z at IP (um)	90	120	140	110	90	120	140	110
Yave	0.11	0.09	0.08	0.11	0.32	0.25	0.23	0.26
Pinch Enhancement	1.46	1.35	1.39	1.43	1.46	1.35	1.39	1.49
Beamstrahlung δB (%)	3.2	3	3	4.6	8.3	8.1	8.4	8.8
Photons per e+/e-	0.86	0.96	1.05	1.17	1.12	1.25	1.38	1.33
Two Linac Length (km)	5	5	5	5.4	9.9	9.9	9.9	9.9



S. Holmes, Fermilab LC Seminar, Page 7

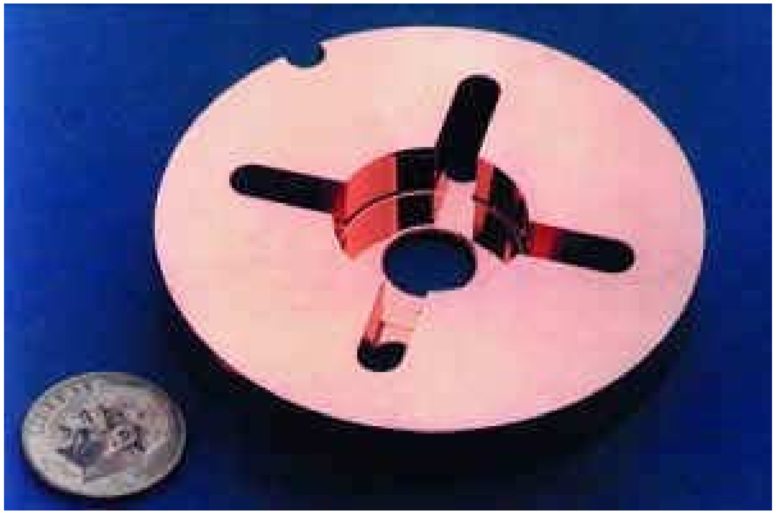
NLC Layout

- Footprint ~30 km

(I believe that a new footprint more SLC-like is under consideration)

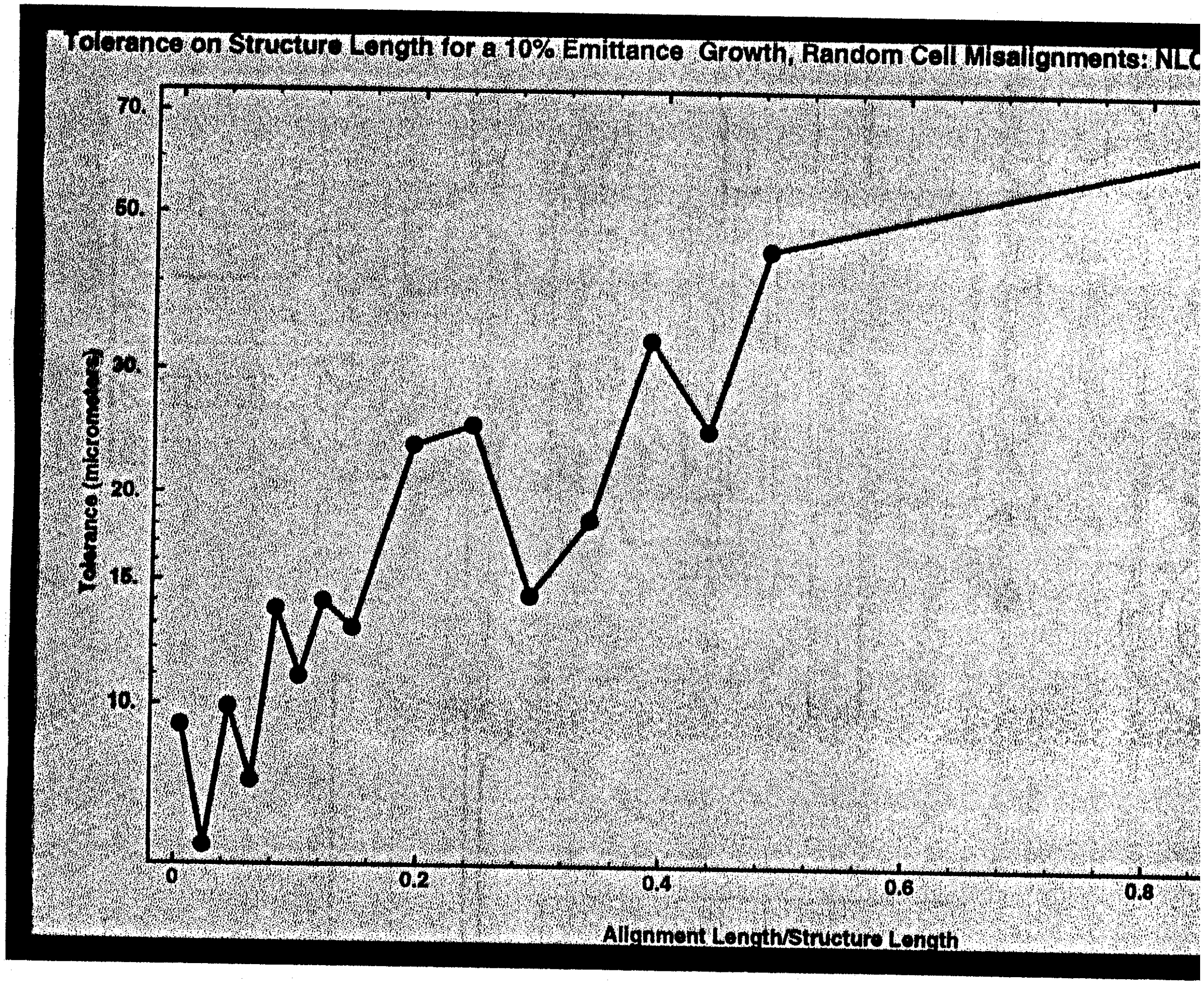
Copper structures

X-band rf - 11.4 GHz



- Normal conducting -> short pulse length-> 3ns bunch spacing
- Small aperture -> wakefields -> component/alignment tolerances
- Large pulsed power -> klystron efficiency -> wall plug power
- High gradients 50 MV/m -> 70 MV/m

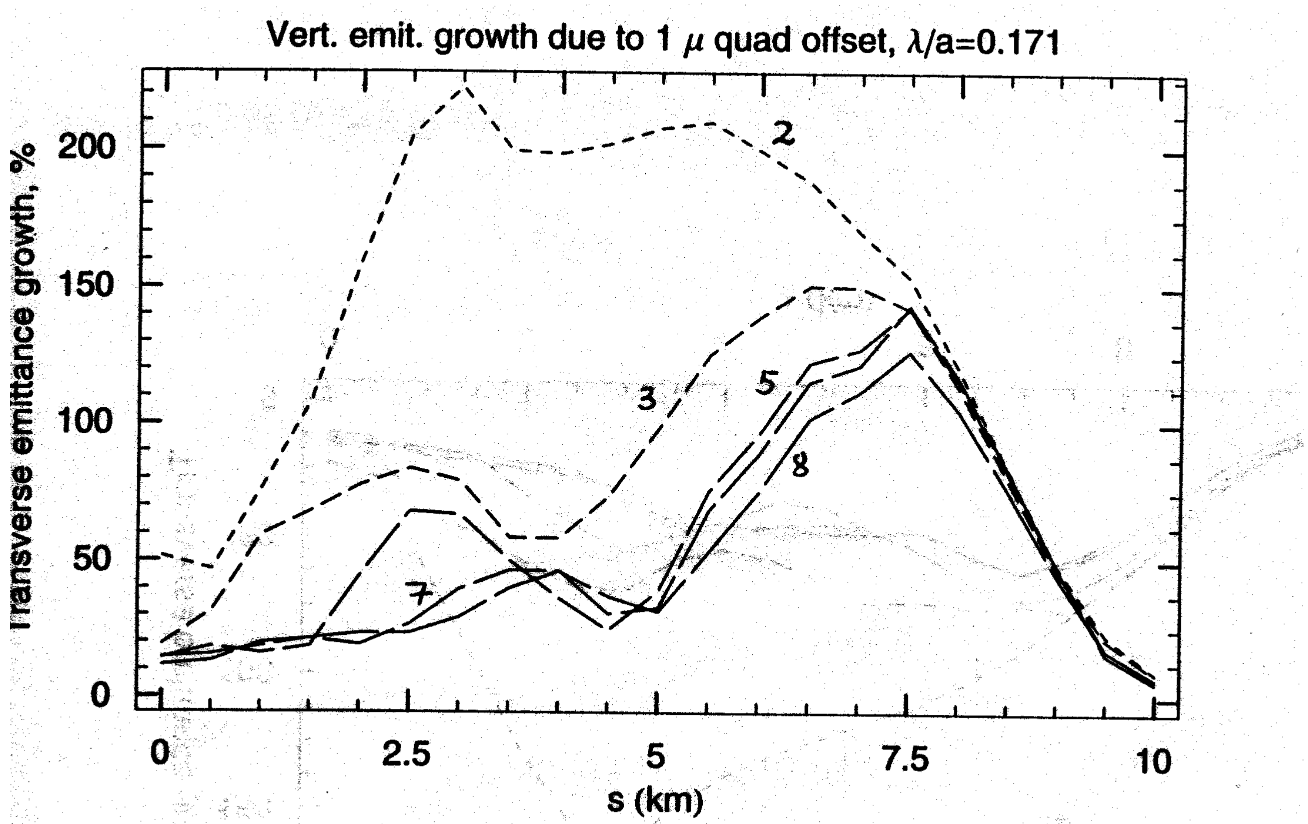
NLC Structure Tolerances



Implies:

- Complex construction
- Controlled environment
- Diagnosability ?
- Industrial production ?

NLC Quad Alignment Tolerances



- Gets worse in the IP's !!
- Ground motion, vibration as well
- BPM-quad offsets

New machine on every pulse ?

NLC Structure damage

Damage Accounting in DDS1

Assumptions:

3000 Hours of Operation at 60 Hz.

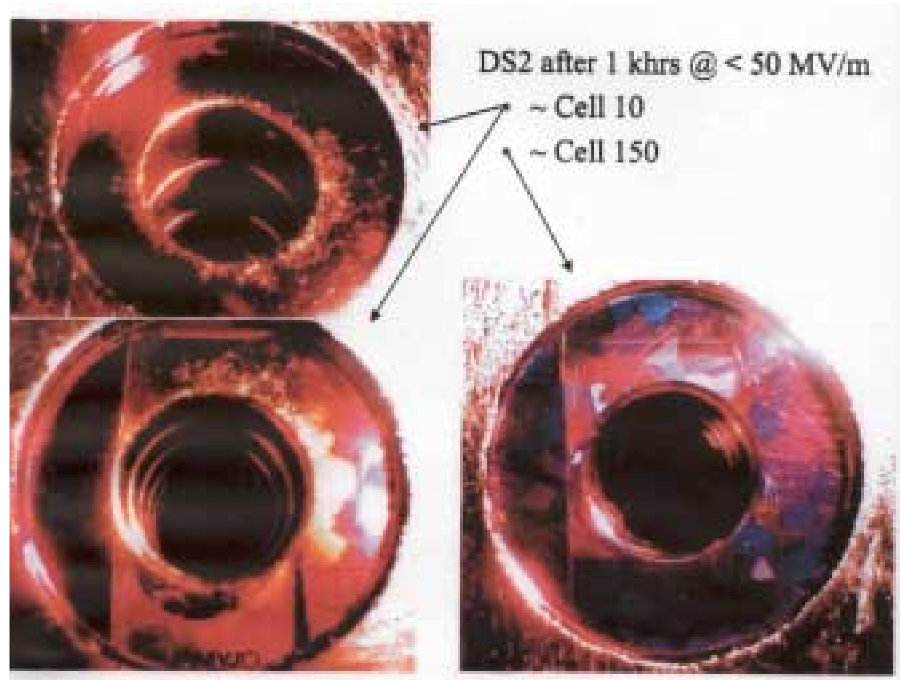
60 degree Phase Shift over 120 Cells (0.5 deg/cell).

10 'Large' Breakdowns per Hour.

At Upstream End of DDS1,

Removing 5 μm of Cu Around the Iris Tip Yields a 0.5 deg Phase Shift per Cell.

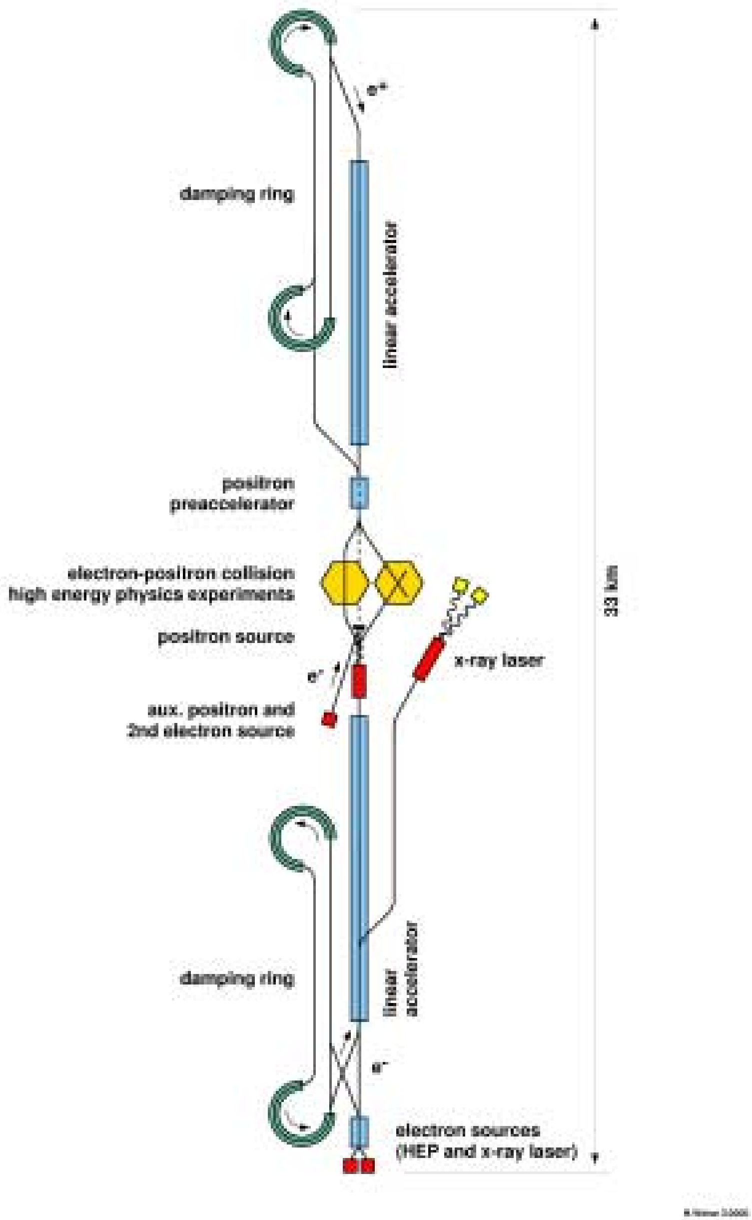
This Corresponds to $120 \times (670\ \mu m)^3$ of Cu Removed or $(106\ \mu m)^3$ of Cu Removed per Large Breakdown ! or $(3.8\ \mu m)^3$ of Cu Removed per Pulse !



During past 12 months progressive damage to the accelerating structures when operated at design gradient has been identified

NLC Status

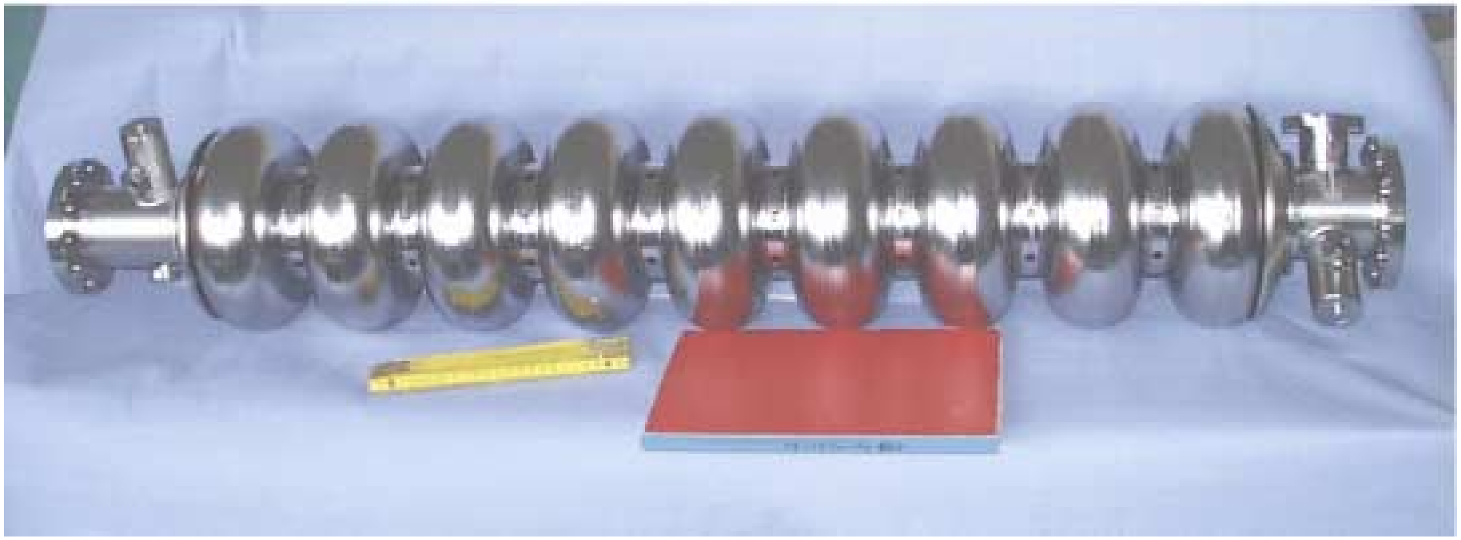
- Accelerating structure degradation/damage not resolved
- Industrialisation of structures not demonstrated
- Very tight tolerances inherent in the design. Ability to meet these tolerances not demonstrated. Probably implies that meeting the design parameters would be difficult
- Collimation not solved yet
- RF power distribution not demonstrated. Real progress on klystrons
- e- & e+ source (damping rings etc) looks O.K.
- Problems get worse with higher energies
- Not Cheap (>>$1B)



TESLA

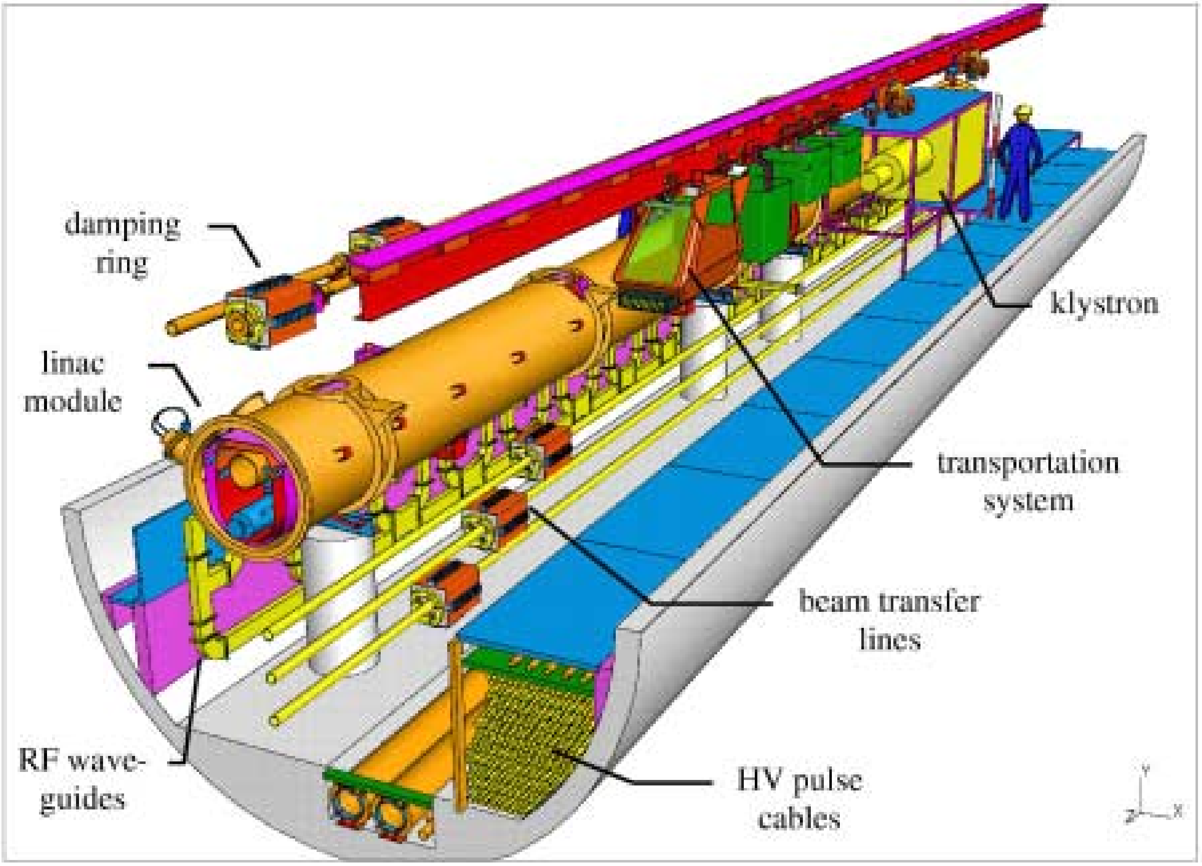
- Footprint similar to the NLC (33km straight line)
- Includes X-ray laser
- Relatively detailed proposal ready to submit to the German Science Council for a 500 Gev machine
- Cost estimate released on March 23rd (I hear ~8B DM european style cost estimate)

TESLA Cavities



- S-band superconducting structures (1.3GHz.)

TESLA tunnel layout



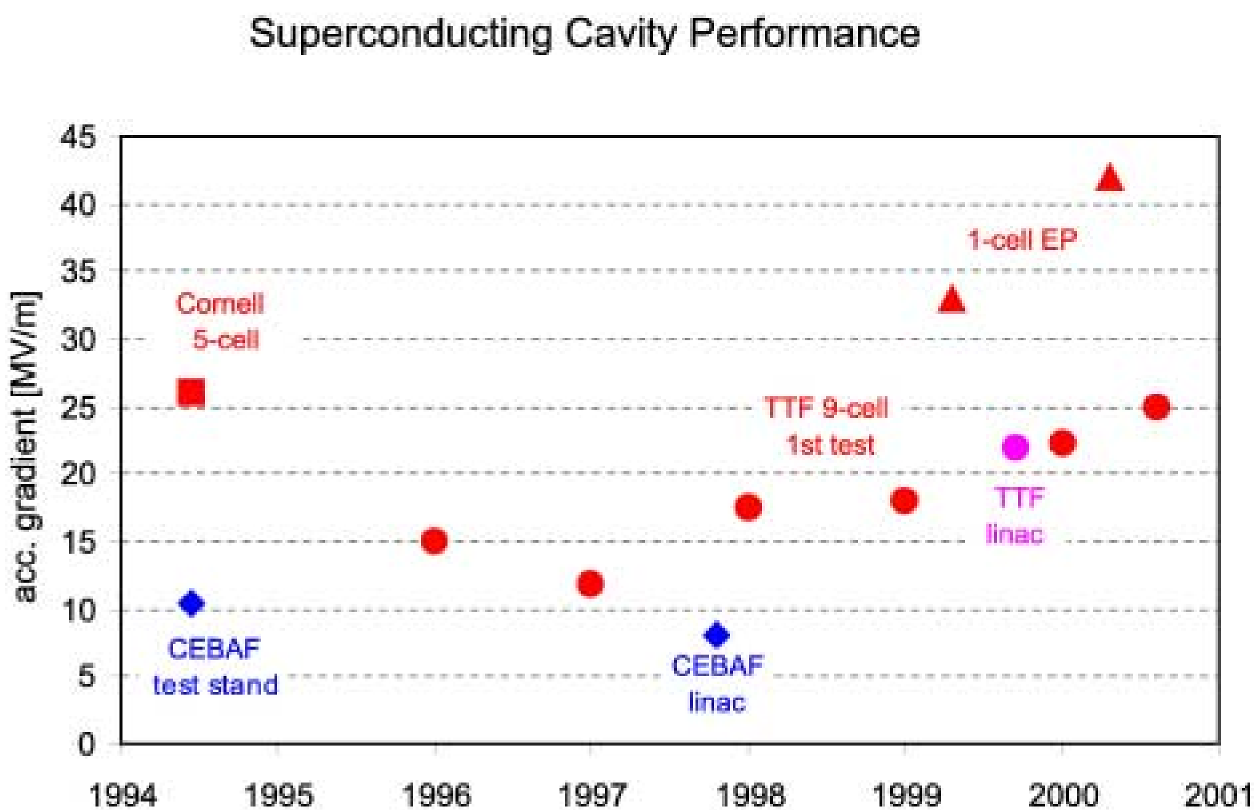
TESLA parameters

Suggested new design parameters for TESLA
(by R.Brinkmann)

	TESLA 500 CDR	TESLA 500 NEW	TESLA 800 NEW
site length km	32.6	32.6	32.6
pulse length µsec	800	950	850
bunches per pulse	1130	2820	4500
bunch spacing nsec	708	337	189
repitition rate Hz	5	5	3
particles per bunch	3.6	2	1.4
emittances at IP 10^-6 m x/y	14/0.25	10/0.03	8/0.01
beamsize at IP nm	845/19	553/5	391/2
bunchlength mm	0.7	0.4	0.3
average energy loss beamstr. δ %	2.5	2.8	4.7
Disruption parameter	18	33	39
AC power MWatt	95	95	132
Luminosity 10^34	0.68	3.1	5

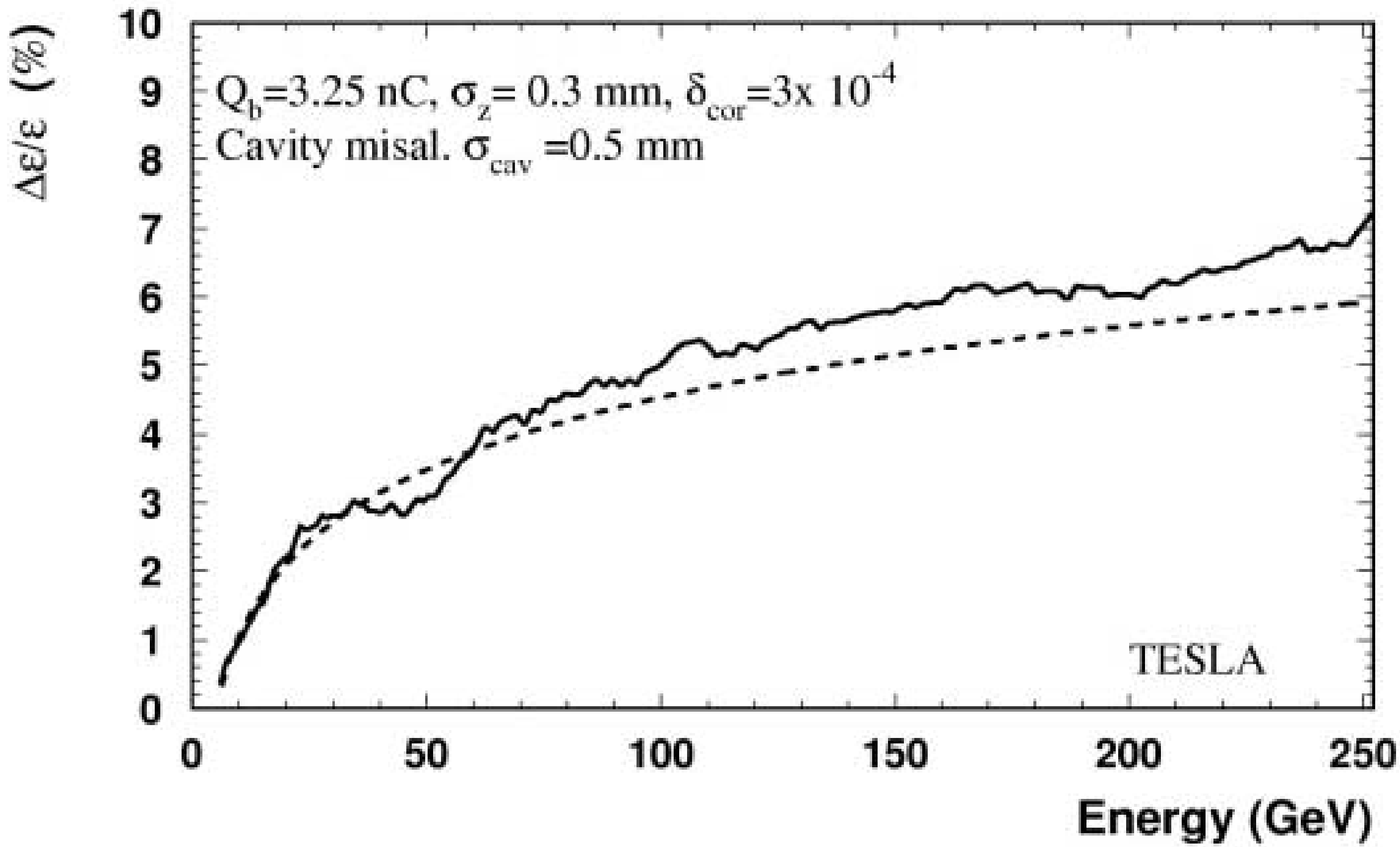
$\times 10^{10}$

TESLA specified at 25 MV/m



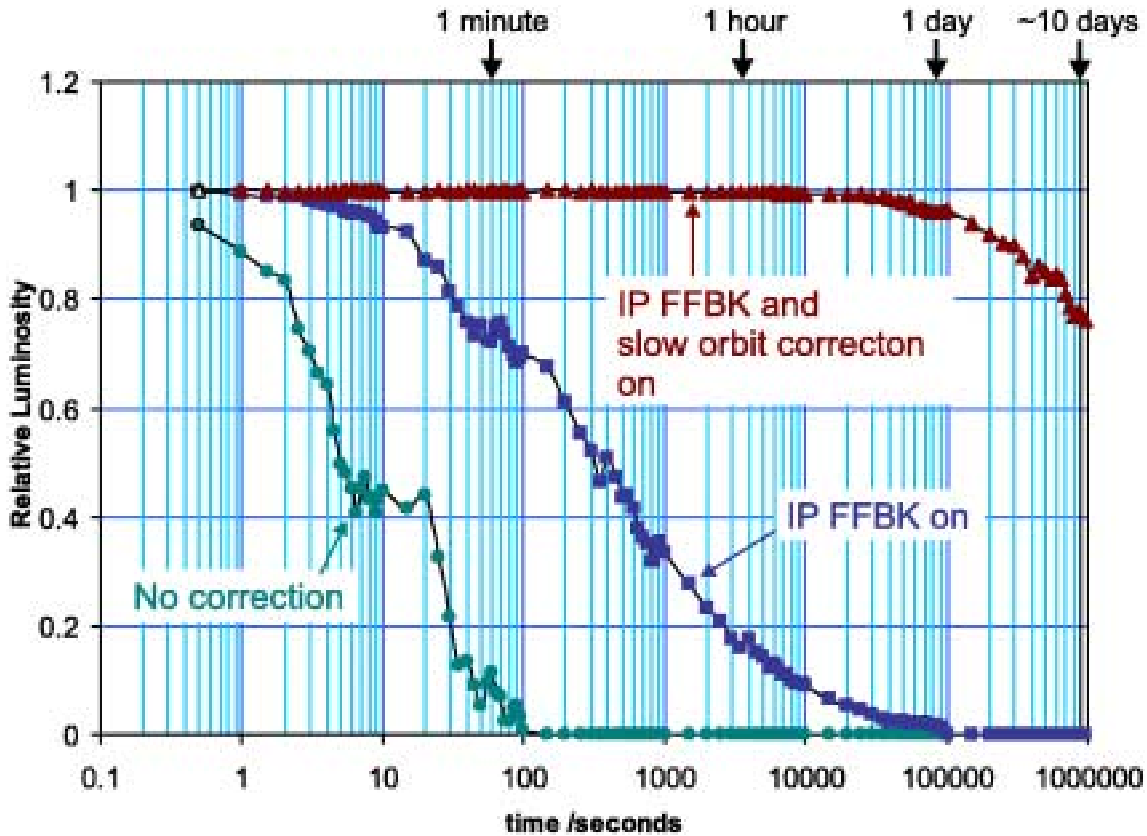
- SC Cavities will not reach the gradient of normal conducting ones

TESLA tolerances



- Larger structure size reduces tolerances on effectively all alignment/component issues
- In addition reduced wakefields from longer bunch train

TESLA Collision Control

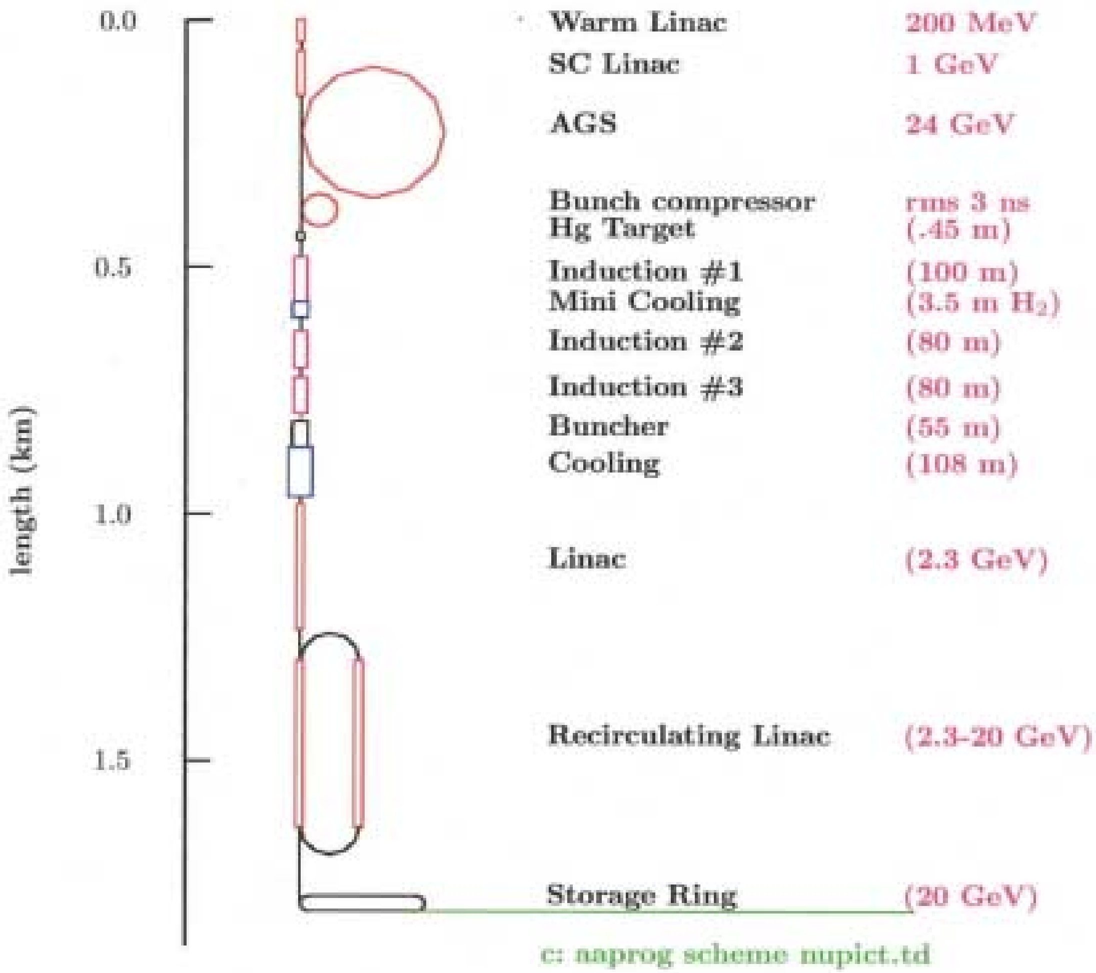


- TESLA not immune to component motion

TESLA Status

- Much more robust technically than the NLC (but still not trivial). If built would probably work.
- Expensive: 500 Gev -> ~$8B (U.S. style estimate). Twice as expensive as the NLC ?
- Formal submission to the German Science Council by the end of March (approval with 50% funding ??)

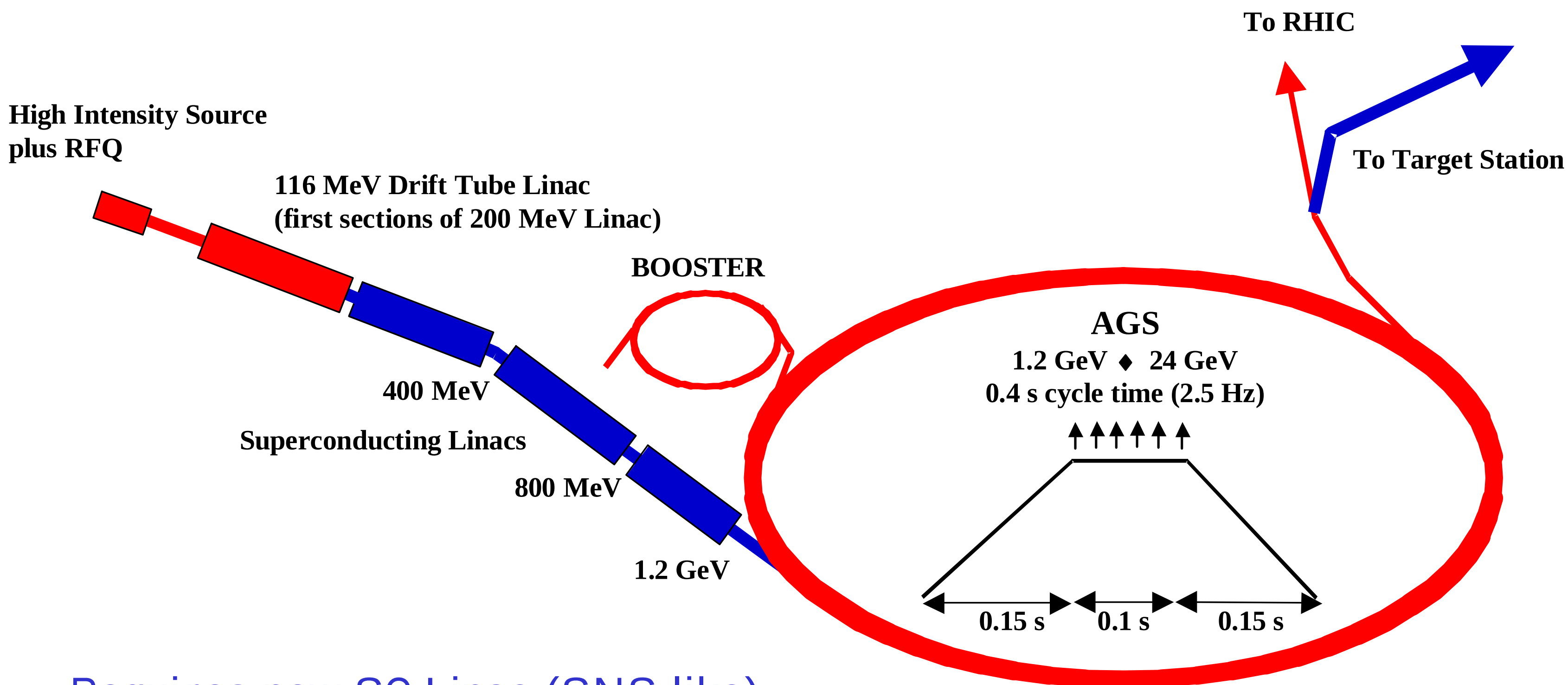
Muon Storage Ring - Study II



Basic Issue is that there is no precedent for a machine of this type hence little experience (both technical and fiscal) for the various components

Enhanced performance over Study 1

Muon Storage Ring - Proton driver



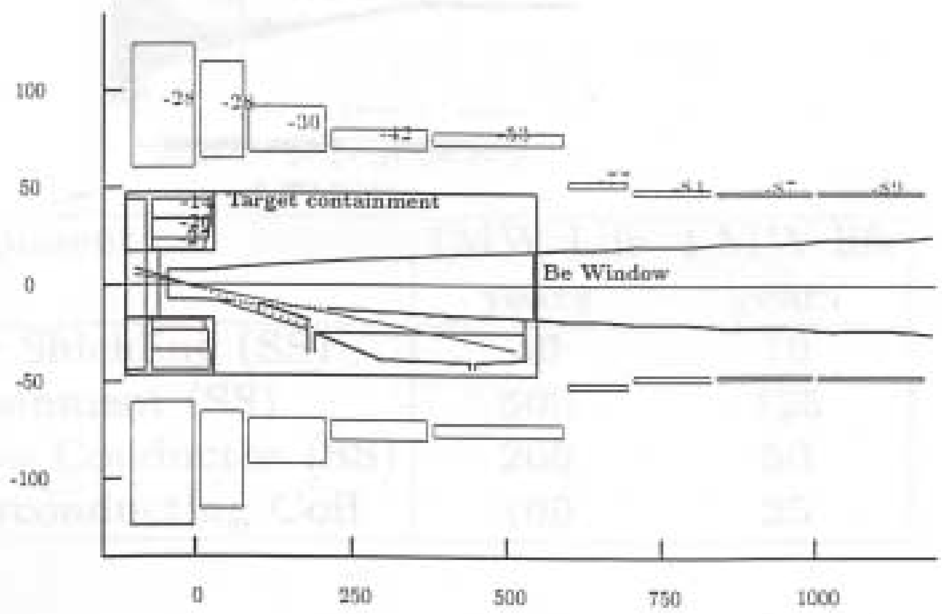
Requires new SC Linac (SNS like)
Can get to 1 MW - probably O.K.

Arguably the least controversial technical component

Muon Storage Ring - Target Station

Target

- 20 T hybrid magnet
- Mercury jet Target
- Mercury pool Beam Dump



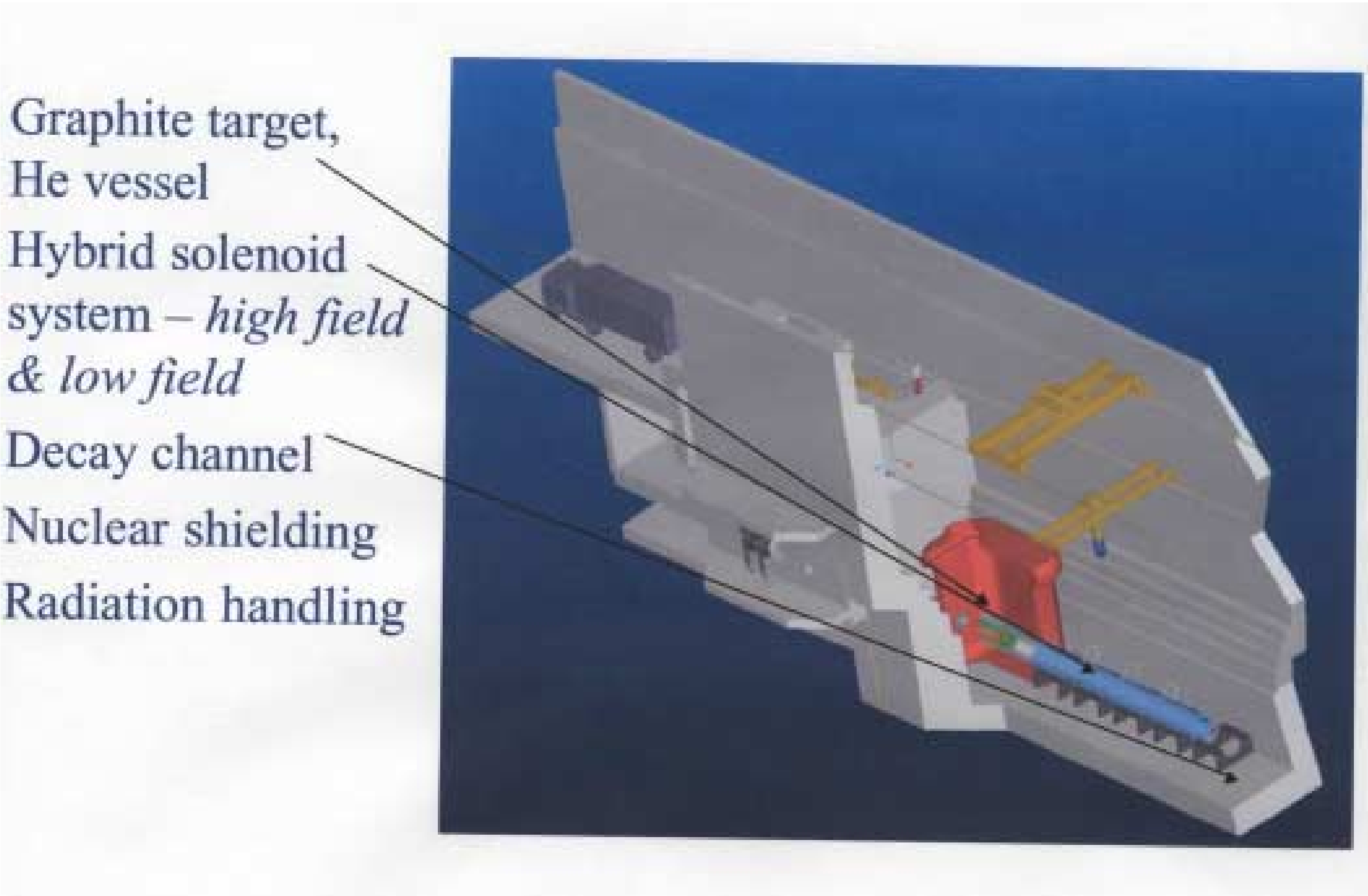
Difficult technical components

Hard to model a mercury jet target - one element of the R&D program

Very high radiation environment (Class III Nuclear Facility ?) requires remote handling

Yields and efficiencies difficult to estimate accurately

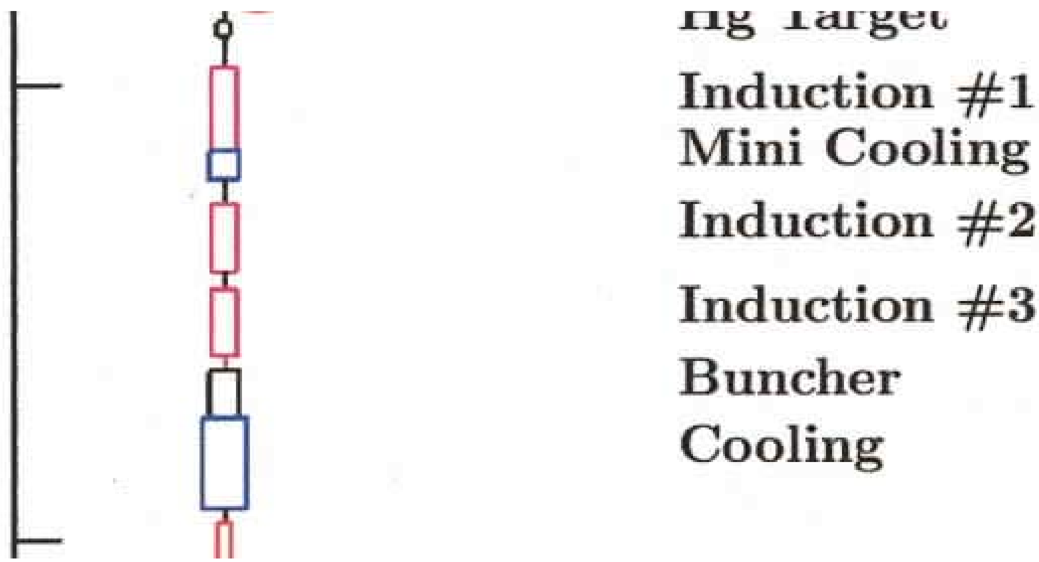
Muon Storage Ring - Target Station



Can you make complicated equipment operate in a remote handling environment ?

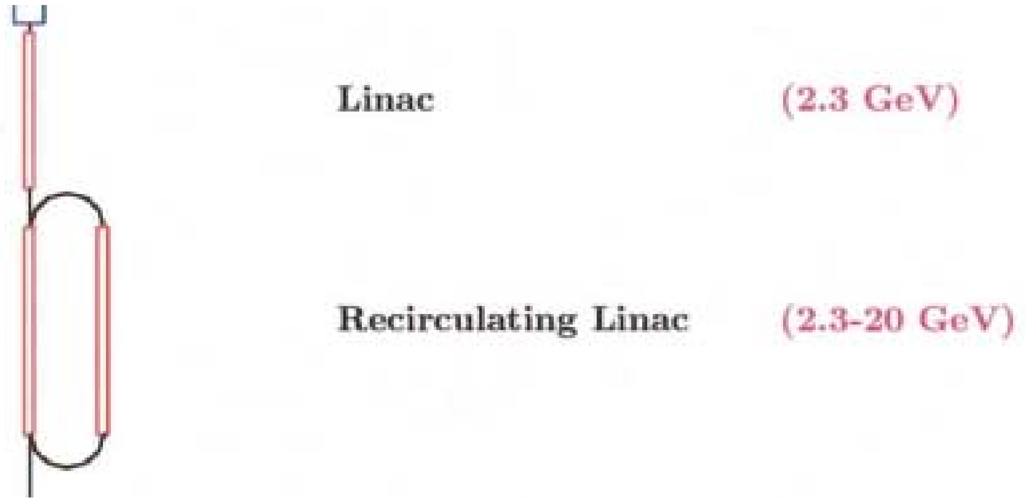
Muon Storage Ring - Capture & Bunching

- Basic problem due to the diffuse nature of the muons coming from the target. Accelerators like small dense beams. Compounded by muon lifetime.
- Multistep scheme involving phase space rotation, bunching, and ionisation cooling (c.f. Pbar production and transfer at the Tevatron). Overall efficiency can easily be less than design



- Many technical components need R&D (some difficult items)
- Transverse Cooling would be nice

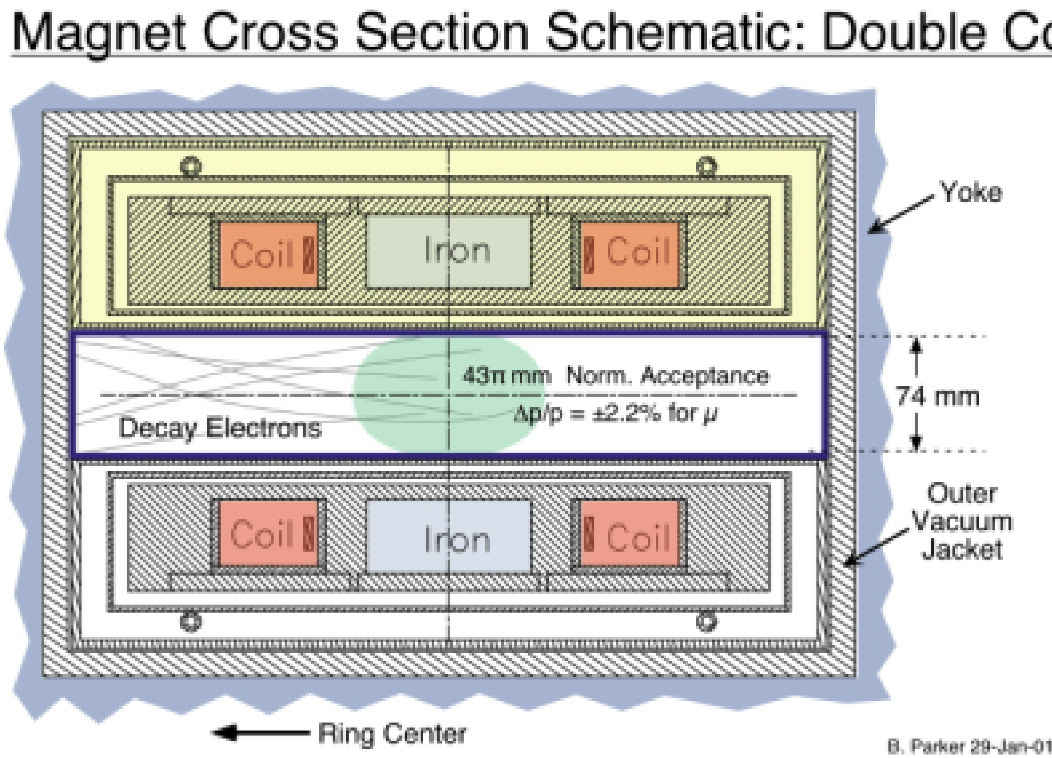
Muon Storage Ring - Acceleration



- Large Beam size (football)
- Requires low frequency (200 & 400MHz) SC rf & power source R&D, would like high gradient 15 MV/m
- Radiation issues

The accelerating sections are probably feasible but expensive

Muon Storage Ring - Decay Ring



- Particle only circulate ~1000 turns makes life easier for the ring
- BNL site conditions require a very compact arc. This is not a generic requirement

Can certainly build something that would work today if necessary. More elegant approach requires some R&D

Muon Storage Ring - Status

- Significant progress continues to be made
- Fundamental difficulties associated with the targeting & capture section
- Many elements need to be prototyped
- Complex multistep process can be expected to be less effective in real life than on paper. (issues remain in diagnostics)
- At least ~5 year R&D program
- Difficult to derive an accurate cost estimate given the comments above

General Features of a 3rd generation hadron collider - (Snowmass 96)

- A discovery machine at the highest energy frontier - 100 Tev center-of-mass (or more !)
- Luminosity 10^{34} -> $10^{35} cm^{-2} sec^{-1}$
- Superconducting magnet technology
- Must be as cost-effective as possible (i.e. it will be expensive)
- Tunnel size starts at ~100km

Potential Design Options

- Snowmass 96 looked at 3 basic machine design options characterised by field strength:
  - Low field ~ 2T (500 km)
  - Medium field 4T - 9T
  - High Field 10T - 12.5T (100 km)
- Medium field represents a 'big' LHC which we presumably understand well enough technically and fiscally. Concentrate on low field and high field. This tends to highlight the differences

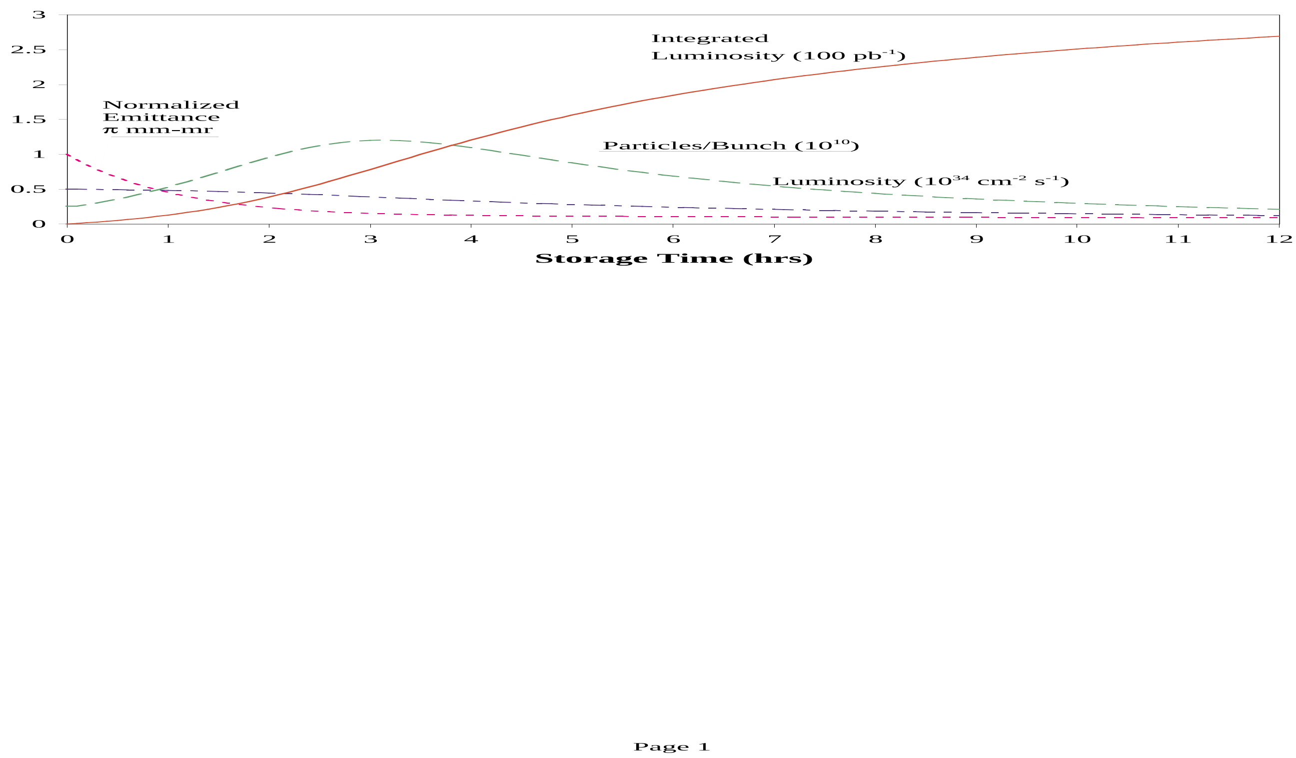
Issues:Low & High Fields

- High Field
  - 50 Tev beam energy at these fields will provide significant synchrotron radiation damping thus robust beam dynamics
  - Minimize physical size
- Low Field
  - Permits the 'low tech' approach and thus potential for greatly simplifying complex systems
  - Possible cost minimum for well known Nb-Ti technology

Principal R&D challenges, high field:
the high-field magnet, handling the synchrotron radiation, IR beam power

Principal R&D challenges, low field:
Large scale of the machine, physics of high beam intensities, beam dynamics/stability

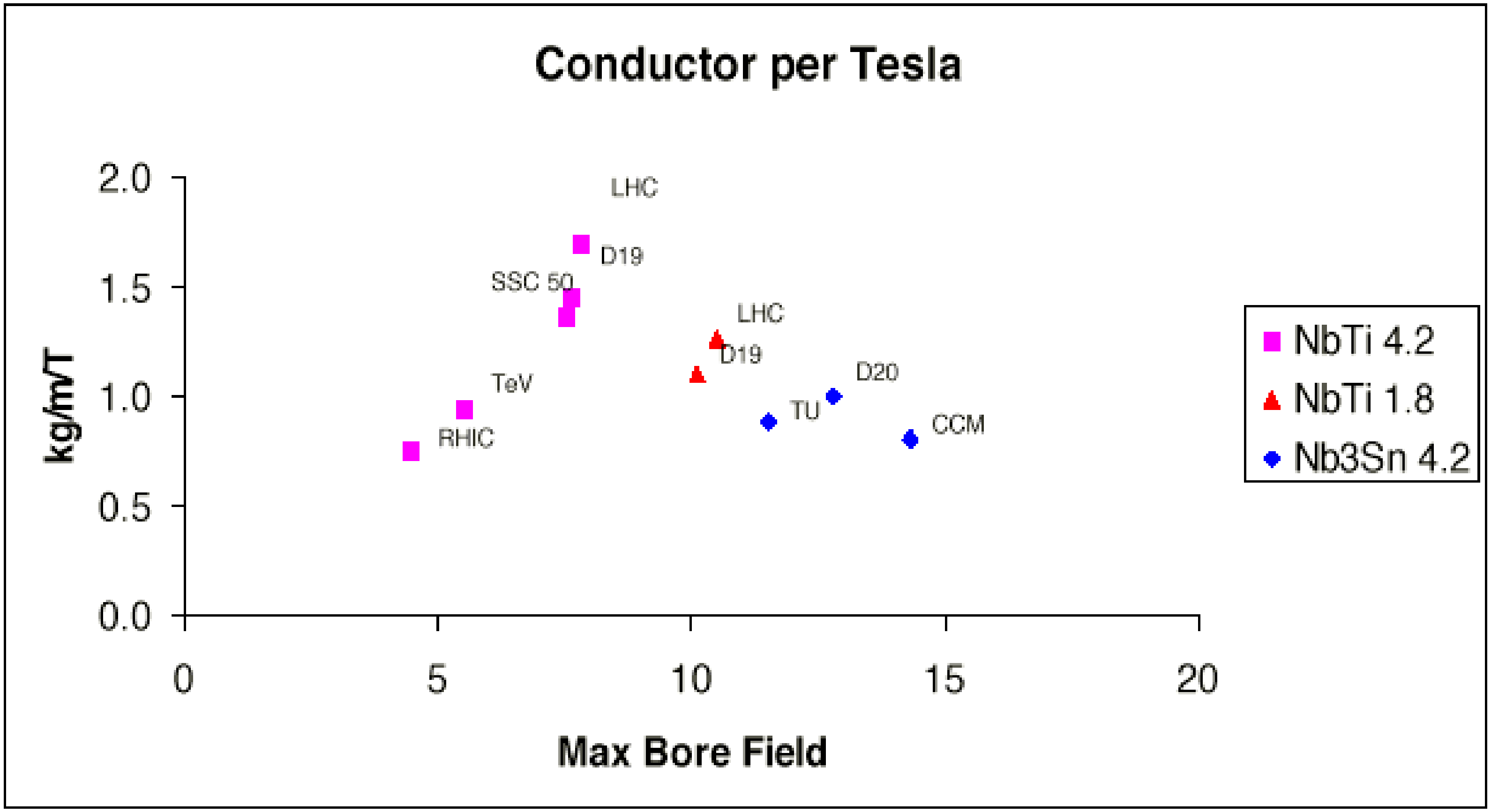
High Field - beam parameter evolution with time from radiation damping



- Decouples Collider performance from injector chain (12 hour integrated Lum essentially independent of initial emittance)
- High density bunches, minimizes bunch intensity
- Robust beam dynamics

High Field - Magnet development

- Focus on Nb_3Sn for conductor development (LBL & Fermilab). Difficult material however.

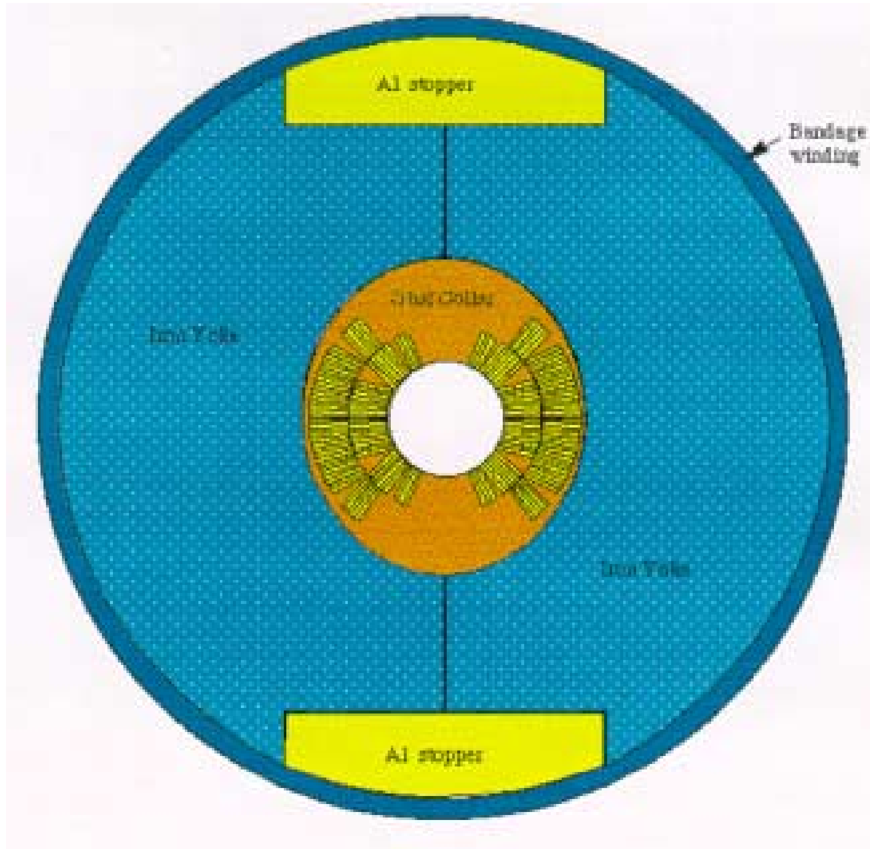


Basic Problem - no high field magnet

Use lessons learned in previous cos θ magnets (mostly NbTi) I.e. focus on the conductor only

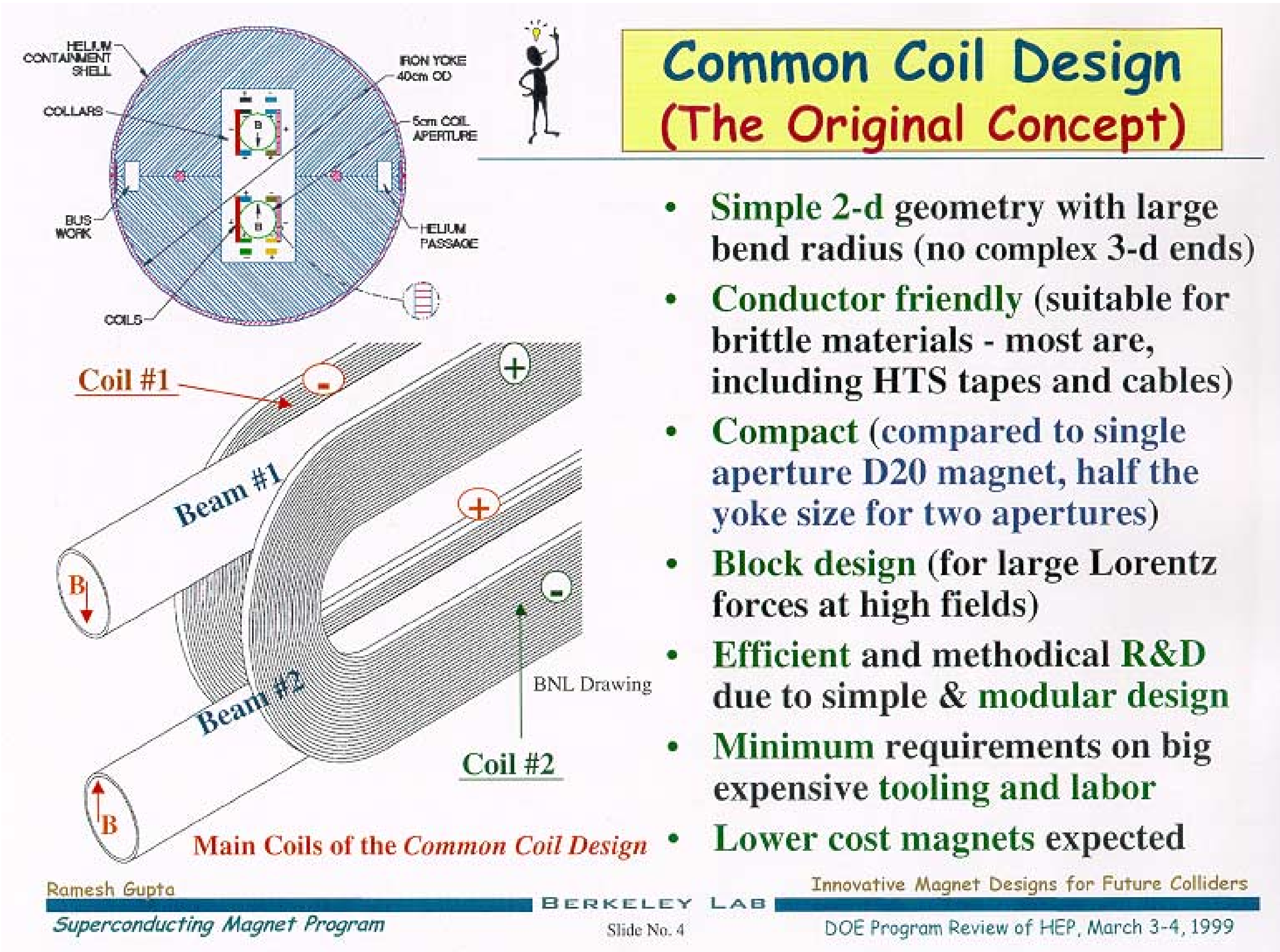
Brittle materials:

- wind & react vs react & wind
- coil impregnation



Fermilab

High Field - Magnet Development



Feasibility Study at Fermilab (with BNL & LBL) in progress now. Will report by ~April.

- Attempt to see whether a staged approach starting with a large tunnel and low-field ring (2T) solves the twin problems of cost & no high field magnet.
  - Phase 1 involves a 230km tunnel and a ~2T dipole giving 40 Tev CMS
  - Phase 2 installs ~10T magnets and raises energy to ~175 Tev
- Uses existing Fermilab accelerator complex in the injector chain.
- In principle the low field technology is understood and will be costed.
- Optimising a 2-stage approach does not result in a fully rational high field design.

VLHC - Status

- Technical design looks more or less O.K. some issues such as IP beam power not resolved
- No 'production ready' high field magnet at this point. Magnet R&D at LBL, Fermilab & BNL is going very slowly. Does not look like an upcoming major project.
- NOT CHEAP. Difficult to quantify this since there is no magnet yet but dramatic lowering of the unit costs are not apparent at this time. High fields -> high mechanical forces
  - The phased approach of a big tunnel with low field magnets is an attempt to spread the high costs over several decades. Whether this makes sense or not will presumably become apparent over the next 6 months or so.

Conclusions

- If you want to start something 'now' (consistent with beam operation in 2010) then you will build TESLA. Major system test complete (TTF). 500 Gev with limited upgrade path.
- NLC will require (at least) a major system test demo(03-05 at Fermilab) before pronounced ready for a construction start. Inherent difficulties with tolerances hence potential performance concerns. Time scale 2015 possibly.
- Muon storage ring requires a (5 year + ?) R&D program to develop prototype components and major system tests on targeting/cooling to establish feasibility. At this point can choose to proceed.
- High field VLHC does not have a magnet (5+ years at least). A phased VLHC could change the thinking about the time scale for how we approach this. Presumably the LHC sets the minimum turn on time for even a phased machine

Nothing is cheap ($1B). All facilities under consideration will cost considerably more than this.